Hydroacoustic Monitoring of Downstream Migrant Salmon and Steelhead at Wells Dam in spring 1984

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ABSTRACT

The downstream migration of salmon and steelhead in spring 1984 at Wells Dam on the mid-Columbia River was monitored using hydroacoustics. The primary objective of this research was to document run tiring and describe the distribution of smolts at the dam. The study occurred from April 2 to June 15, 1984.

Four transducers were deployed at the bases of pier noses at Turbines 3, 5, 7, and 9 and aimed up **24°** into the forebay. They were sampled once every hour, 24 hours per day, for 75 days.

An index of fish passage was reported daily to the Water Budget Center in Portland, Oregon. This index was computed as follows. For each 24-h period, separate fish passage rates (number/tire) at each of the four sampling locations were estimated by dividing the sum of the 'weighted" fish detections by total sample time. These four values then were averaged to produce the daily index (number/day/location).

The first substantial increase in fish passage occurred on April 25, 1984 due to the chinook released from the Winthrop hatchery on April 23. During May, run timing was fairly uniform except for peaks on May 2, 14, 18, and 22. The unexpected peak in run size that occurred from May 29 to June 2 could have been caused by juvenile mountain whitefish. Although the proportion of each species varied, chinook passage probably peaked in late April, and steelhead in the first two weeks of nay; sockeye passage was variable throughout the study.

The data indicated that most downstream migrants were distributed high in the water column and toward the western end of the dam. Average hourly passage rates for day and night were similar, but more fish passed the dam during the longer period of daylight than the shorter period of darkness.

ACKNOWLEDGEMENTS

Studies like this are successfully completed because of a lot of hard work by many people. Our heartfelt thanks to employees of Douglas County PUD, the Water Budget Center, and BioSonics for all their help.

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1.0 INTRODUCTION

1.1 Background and Objectives

At Wells Dam on the mid-Colunbia River, the Bonneville Power Administration (BPA) and Douglas County PUD (DCPUD) contracted BioSonics, Inc. to monitor the 1984 downstream migration of salmon and Steelhead smolts. Research at Wells is important because two of the three major tributaries of the mid-Columbia, the Okanogan and Methow rivers, empty into its reservoir (Figure 1). The Okanogan carries the northernmost Columbia anadrorous fish runs, including wild sockeye salmon from Lake Osoyoos. Hatchery-raised chinook salmon and steelhead trout are released in both the Okanogan and Methow drainages.

The primary purpose of the spring 1984 monitoring study at Wells Dam was to document the timing and magnitude of the out-migration. An index of run magnitude was reported daily to the Water Budget Center in Portland, Oregon. The data collected for the index were also used to describe the vertical, horizontal, and die1 distributions of outmigrants at the dam. The specific objectives of this research were to:

1) Provide daily acoustic indices of fish passage between April 2 and June 15, 1984.

2) Estimate the vertical, horizontal, and die1 distributions of outmigrant in the forebay immediately in front of the dam.

To help interpret the fish data, a hydrographic description of flow through the dam is provided. Species composition data, obtained from Wells fyke net catches and upstream hatchery release information, are also included.

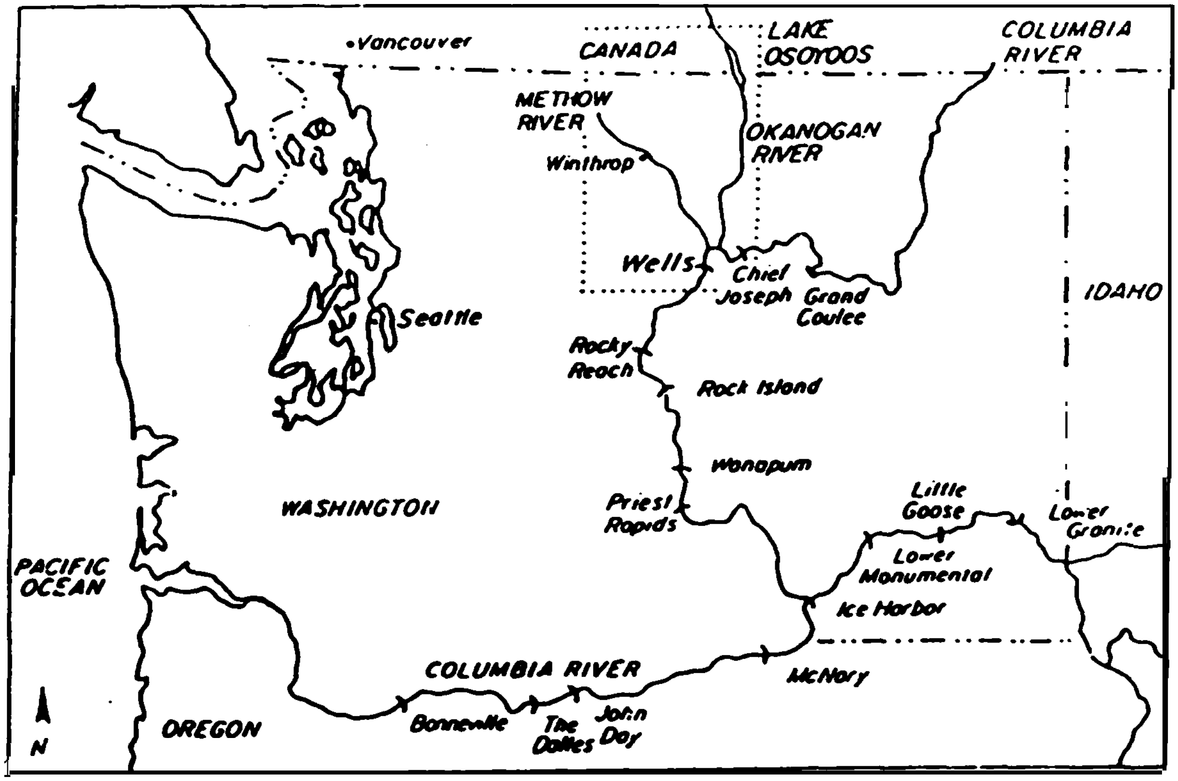

Figure **1. Location** of Wells **Dam on the** Columbia River. Area within dotted lines is shown in Figure 4.

1.2 study Site Description

Wells Dam was designed with spill intake8 above turbine intakes (Figure 2) to take advantage of about 1000 ft of basaltic bedrock across the Columbia at its location. As such, it is the only hydrocombine in the Western Hemisphere. The spill bay and turbine intake floors are 70 ft and 130 ft from the surface, respectively. Because the spill bays are over the turbine intakes, spill and turbine operations have a combined effect on flow patterns in the forebay.

Wells Dam has 10 turbines and 11 spill bays, numbered consecutively from west to east(Figure 3). Each turbine has three intake slots, designated A, B, and C from west to east. **Intakes** B and C of Turbine X and Intake A of Turbine **X+1** are immediately below Spill Bay **X+1;** Spill Bay 1 has no turbine beneath it. ***For*** the purposes of this report, **a** 'Section' at Wells is defined as the composite of Turbine X and Spill Bay X+1. Descriptive data on the dam are presented in Table 1.

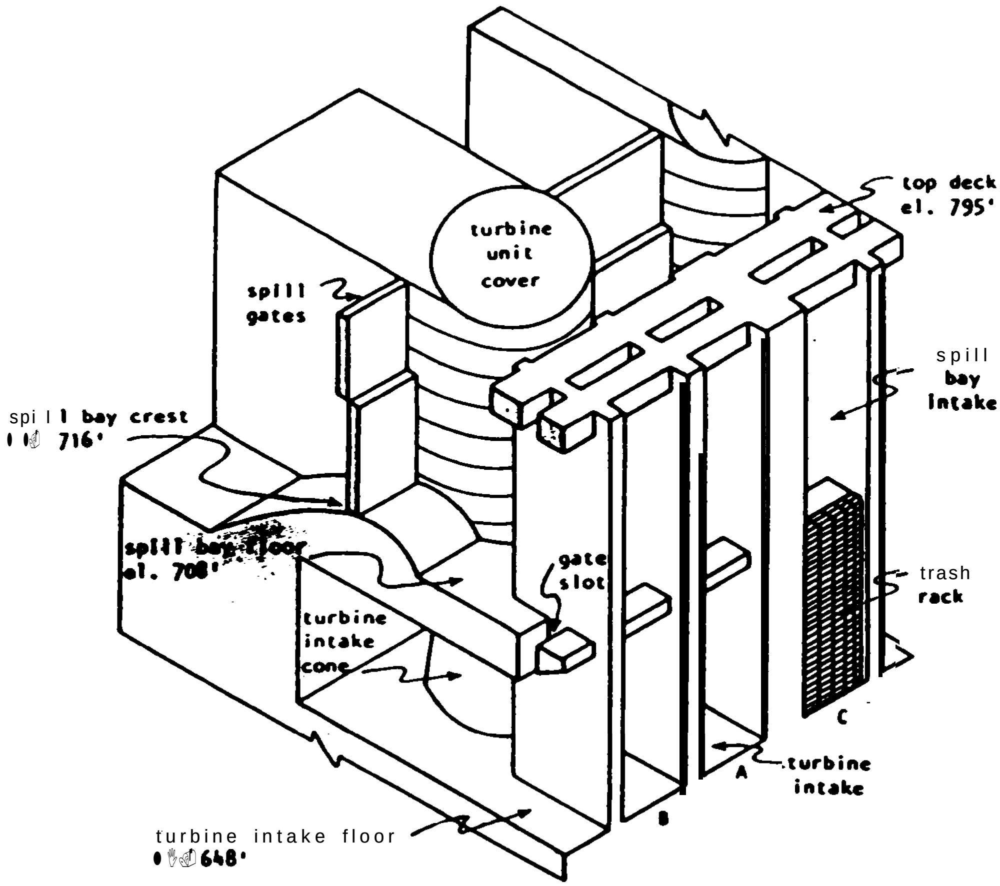

Figure 2. isometric view of Wells Dam showing Turbine Intake8 A, B, and C, and spill bay arrangement. In this view, Intake Cgoes to (X) and Intakes *A* and B go to Turbine (X+1).

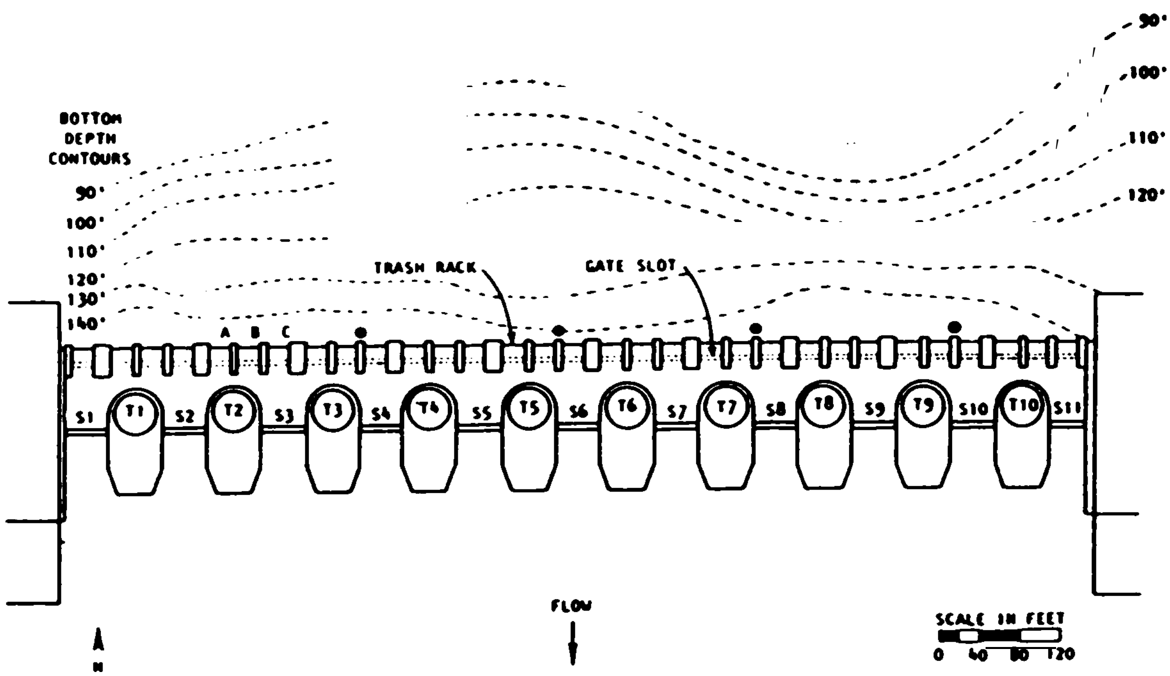

Figure 3. Plan view of Wells Dam showing Spill Bays l-11 and Turbines l-10. Location8 of forebay monitoring transducers are indicated by black dots.

Table 1. Descriptive data for Wells Dam for reservoir elevation 779 ft HSL.

River	Columbia River
river Mile at Dam Site	515.8
Drainage Area	85,300 sq mi
Historical Flood (1894)	657 kcfs
Spillway Design Flood	1,180 kcfs
Normal Reservoir Elevation	771 to 779 ft MSL
Gross Head (maximum)	74.5 ft
Reservoir Storage Capacity	300.000 acre-ft
Reservoir Length	30 mi
Dam Length (overall)	4.460 ft
Hydrocombine Length	1.130 ft
Hydrocombine Height	185 ft
Generating Units	10
Type of Turbine	Kaplan
Maximum Capability	820.000 kilowatt8

1.3 Hydroacoustics

Outmigrant passage through Wells was studied using fixed-location hydroacoustice. Carlson (1982) provide8 a detailed explanation of these techniques. The components and operation of the hydroacoustic systers used at Wells in 1984 are explained in Appendix A. The primary data from the hydroacoustic systems were recorded on echograms. Data acquisition from the echograms is explained in Appendix B. Data reduction, including weighting procedures and the derivation of the primary statistics, is described in Appendix C.

2.0 Methods

2.1 Transducer Orientation8

Based on the results of the 1983 monitoring study at Wells for which ten forebay transducers were used, it was determined that four sampling location8 distributed evenly across the dam could provide sufficient data to document run timing. In 1984, four 15° transducers were deployed 125 ft deep at the bases of the pier noses separating the B and C-intakes of Turbines 3, 5, 7, and 9 (Figure 3). These transducers, designated T3, T5, T7, and T9, were aimed upward as close to the dam as possible without causing acoustic returns from the da.. The resulting vertical aiming angle was 24° upward into the forebay.

2.2 Sampling Design

Systematic hydroacouatic sampling was performed 24 h/d from April 2 to June 15, 1984 at the 4 pier nose transducers. Each transducer was interrogated once each hour for 12 min at an acoustic pulse rate of 4 pulses/sec. Passage rate and distribution data (vertical, horizontal, and die1) were derived from these transducers.

2.3 Statistical Methods

Daily indices of run timing at Wells Dam were made using acoustic data from the 4 pier nose transducers. For each 24-hour period, fish passage rates (#/day) for each monitoring location were estimated by dividing the sum of the weighted fish detection8 by total interrogation time (min) and multiplied by 1440 min per day. These 4 values were then averaged to produce the daily index (#/day/location). This daily index (0000-2359 h) was reported at 0800 h the following day.

It was not necessary to adjust the index for dam operations (i.e., shutdown turbines and closed spill gates) for the following reasons. The midpoint of the acoustic beam from transducers aimed obliquely into the forebay intersected the surface approximately 63 ft from the dam. At this distance from the dam, fish detected in the upper part of the water column might not necessarily have passed into the turbine or spill bay where that transducer was located. Also, adjacent turbines are connected in pairs to one transformer (i.e., Turbines 1 and 2, 3 and 4, etc.); at no time is one pair of turbines loaded and another not. It was originally planned that data from a given sampling location would be excluded from the index estimate when the turbine at that location and two adjacent turbines were cff and the three adjacent spill gates were closed. However, this turbine/spill gate configuration occurred only for parts of 11 of 75 days. Since the difference in the index with and without this data was relatively small (average 4.1%), the reported index was based on data from all 4 locations for all 75 days.

The primary data for the vertical distribution analysis were individual weighted fish detections, which were reduced to cumulative distribution functions (see Appendix D for vertical distribution methods). The horizontal and die1 distribution analyses were based on the hourly estimates of fish passage **(#/hr)** derived from the 12 min/hr interrogations at each pier nose transducer. Data reduction and derivation of the primary statistics for these analyses are described in Appendix C.

For the vertical, horizontal, and die1 distribution analyses, the study period was divided into three season blocks (Table 2). Block 2 coincided with the prototype and spill studies. All data from a given location within a given block were combined. All tires are presented in 24-h Pacific Daylight Time (PDT). Periods of day and night for each block were defined using sunrise/sunset tables (Table 2).

Table 2. Definitions of season blocks and day and night periods (PDT) for each block in 1984 at Wells Dar.

Block	Dates	**Day**	Night
1	April 2 to April 29	0600-2000	20004600
2	April 30 to May 25	0500-2000	2000-0500
3	nay 26 to June 1s	0500-2100	2100-0500

3.0 Results

3.1 Project Discharge and Dam Operations

Mean daily project discharge for April 1984 was 136.7 kcfs or 114% of the 1S-year average. For nay it was 132.0 kcfs or **84%,** and for June it was 131.6 kcfs or 751.

Spill levels mandated by the Federal Energy Regulatory Commission (FERC) were 25% of the previous day's inflow between April 26 and April 30 and 20% between nay 1 and May 24. PERC spill occurred mostly between 2000 and 0600 h in -the curter five spill bays of the dam. Turbine loading was greatest during day-light hours and was spread evenly across the dam. The methods and more results concerning project discharge and dam operations are presented in Appendix E.

3.2 Run Timing and Species Composition

3.2.1 Species Composition

The three principal salronid species migrating past Wells Dam in April and May are: chinook salmon **(*Oncorhynchus tshawytscha*),** steelhead trout (*Salmo gairdneri*) and sockeye salmon **(*Oncor-hynchus nerka*)**.

About one million hatchery fish were released at five locations in the Okanogan and Methow rivers between April 16 and May 8, 1984 (Table 3 and Figure 4). An early release of 363,000 spring chinook from the Winthrop hatchery occurred on December 25, 1983 because the rearing ponds began to freeze. The largest single release was 620,000 chinook from Winthrop on April 23. About 467,000 steelhead raised at the Wells hatchery were released at 4 sites upstream of the dam between mid-April and early May.

DCPUD set a fyke net inside Turbine Intake 4C intermittently during the 1984 hydroacoustic studies. The fyke net data indi-cated that wild sockeye and hatchery-raised chinook and steelhead were passing wells in varying proportions during the sampling season (Figure 5). No one species was predominant, except for chinook in late April and sockeye on May 14 and 16. Although it was not possible to divide the season into species-specific periods of tine, chinook passage probably peaked in late April and steelhead in the first two weeks of Hay; sockeye passage was variable throughout the study. The net catches during April and nay were dominated by chinook, steelhead, and sockeye.

Table 3. Species, locations, distances from Wells, dates, and sizes of releases of hatchery-raised juvenile salmonids upstream of Wells Dan in December 1983 and spring 1984. Sources : B. Wallien (USFWS) and S. Miller (WDG).

Species	Release Site	niles from Wells	Date	Number
spring chinook	Winthrop	50	12/25/83	363,000
			4/23/84	620,000
summer steelhead	Similkameen	90	4/16-24	76,000
	Twisp	45	4/17	14,000
	Chewack	60	4/17-I 8	21,000
	Methow	10	4/20-5/8	356,000
			Total =	1,450,000

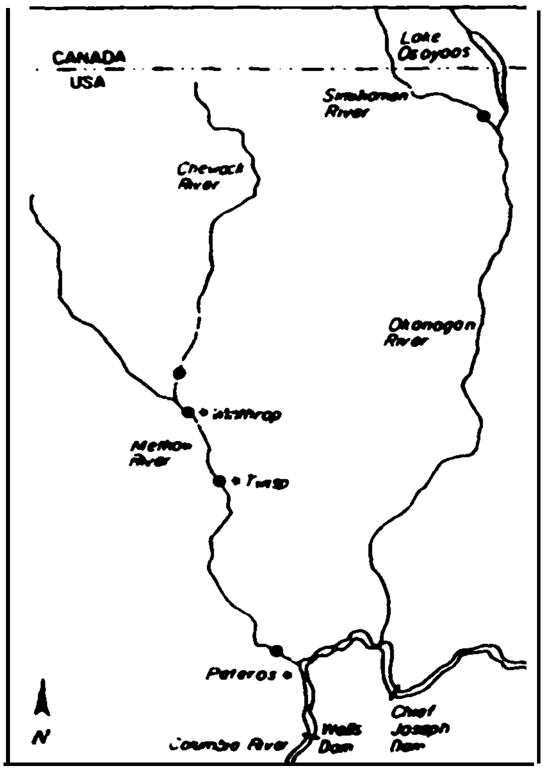

Figure 4. Location of salmonid release sites (●) upstream of Wells Dam for spring 1984. (*) designates a town.

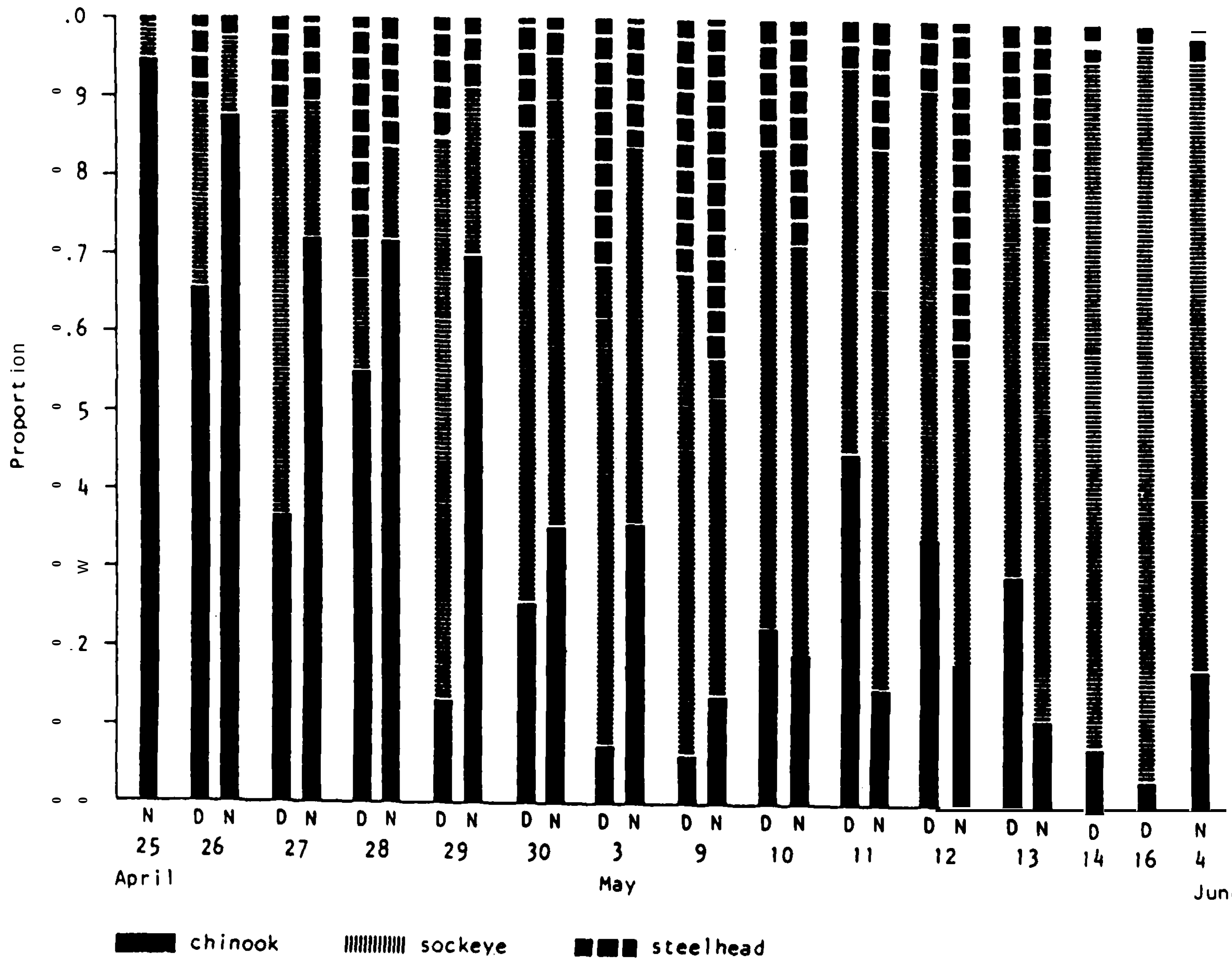

Figure 5. Proportions of chinook, sockeye, and steelhead out of the total (chinook+sockeye+steelhead) for each fyke net sample from Turbine Intake 4C. D=day, N=night. Wells Dam, spring 1984.

A special fyke net sample was taken on June 4. This set caught moatly juvenile lamprey and juvenile mountain whitefish. The implications of this observation are discussed in the next section (3.2.2).

3.2.2 1984 Run Timing

Acoustic monitoring began on April 2, but the first substantial increase in passage was not recorded until April 25 (Figure 6). The April 26-28 peak was probably due to the chinook released on April 23 at Winthrop, implying that it takes most chinook between 2 and 5 days to migrate the 50 miles between Winthrop and wells Dam. (Similar travel time estimates were made in 1982 and 1983.) During nay, run tiring was fairly uniform except for peaks on May 2, 14, 18, and 22 (Figure 6).

In 1984, hydroacoustic sampling extended into June for the first tire at Wells. An unexpected increase in run size occurred on May 29 and lasted until June 2. To determine whether this peak could have been caused by lamprey and/or mountain whitefish, which dominated the fyke net catch on June 4, their target strengths (acoustic sites) were measured using dual-beam techniques (Ehrenberg 1982). The results showed that the acoustic size of lamprey juveniles was much smaller than that of salmon and steelhead smolts and was below the threshold of the hydroacoustic system, thus, lamprey were not being detected. The acoustic site of whitefish juveniles was similar to that of salmon and steel head smolts and therefore, it was possible that the surge in run magnitude around May 29 to June 2 was caused by whitefish. However, we cannot be certain of this because no net data were collected during the peak in question.

Run tiring was markedly different between 1982, 1983, and 1984 (Figure 6 and Appendix F). The bimodal run timing curve observed in 1982, which was attributed to temporally separate chinook and sockeye migrations, was not observed in 1983 or 1984 (BioSonics 1982, 1983). This was partly because there is substantial yearly variation In the timing and magnitude of the sockeye outmigration from Lake Osoyoos- Also, run tiring at Wells Dar is affected by the yearly variation in the dates, sixes, and locations of the releases of hatchery-raised fish upstream of the dam.

The daily index values for spring 1984, as well as 1982 and 1983, are presented in Appendix F.

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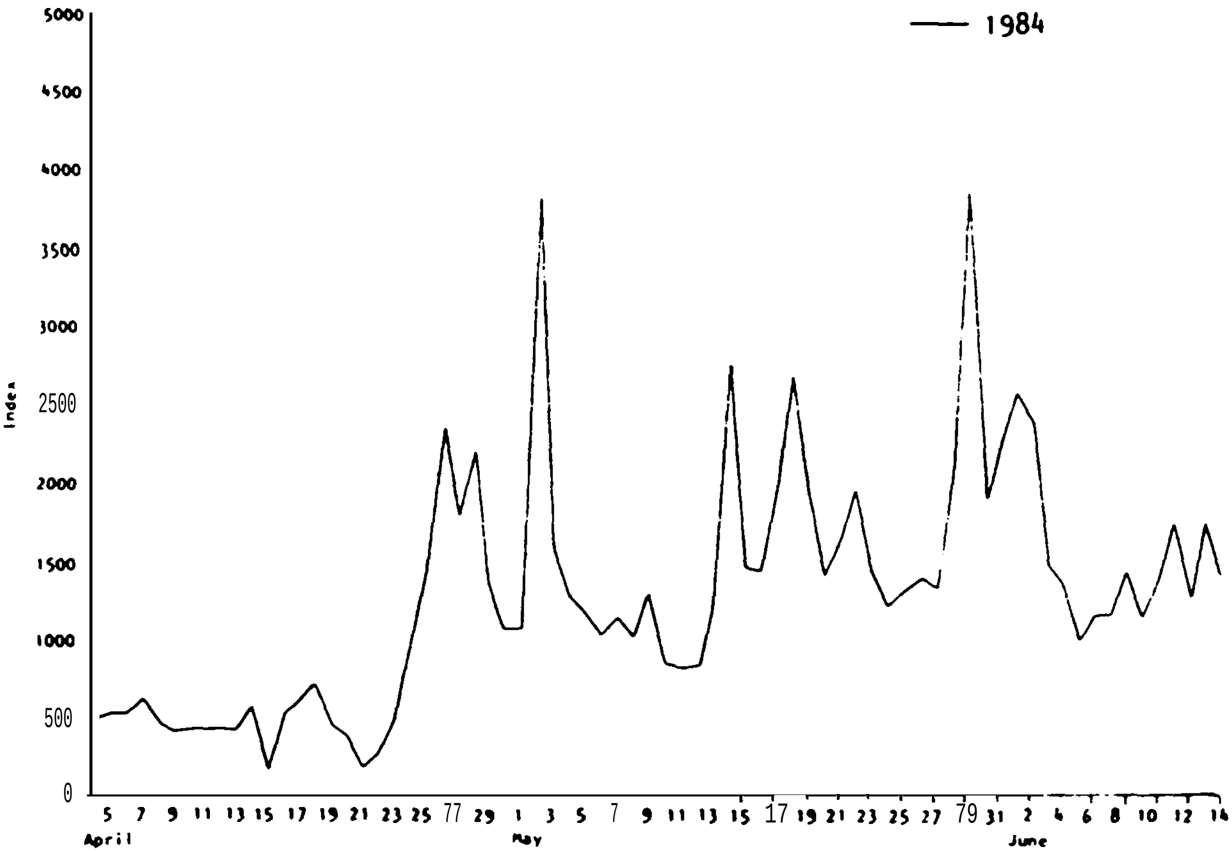

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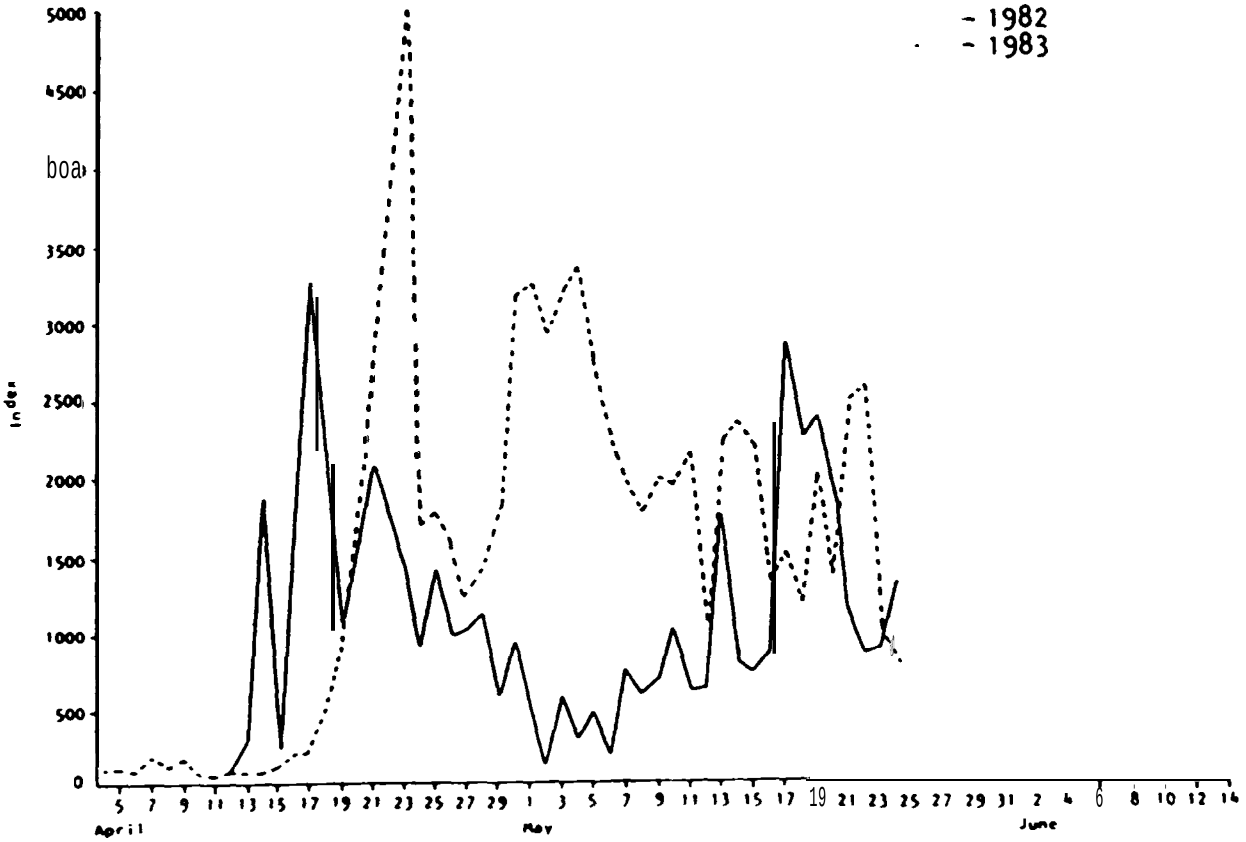


Figure 6. Daily fish passage indices (mean #/day/location) for (a) spring 1984 (T3+T5+T7+T9/4) and (b) spring 1982 (T3+T5+T6/3) and spring 1983 (T1+...+T10/10) at Wells Dam.

3.3 Vertical, Horizontal, and Die1 Distributions

3.3.1 Vertical Distribution

A comparison of vertical distributions for low and high spill proportions for constant day or night conditions in Block 1 indicated that fish were distributed deeper at the higher proportion of spill (Table 4). A similar result was obtained in 1983. During Block 2, the opposite was observed (Table 4 and Figures 7a,b). During Block 3 there was little spill, so this comparison could not be made.

The comparison of day and night vertical distributions for a constant spill range indicated that fish were deeper during night than day for Blocks 2 and 3 (Table 4 and Figure 7c,d). The opposite was true for Block 1.

In 1983 for all data from April 4 to Hay 26 combined, fish were deepest at night.

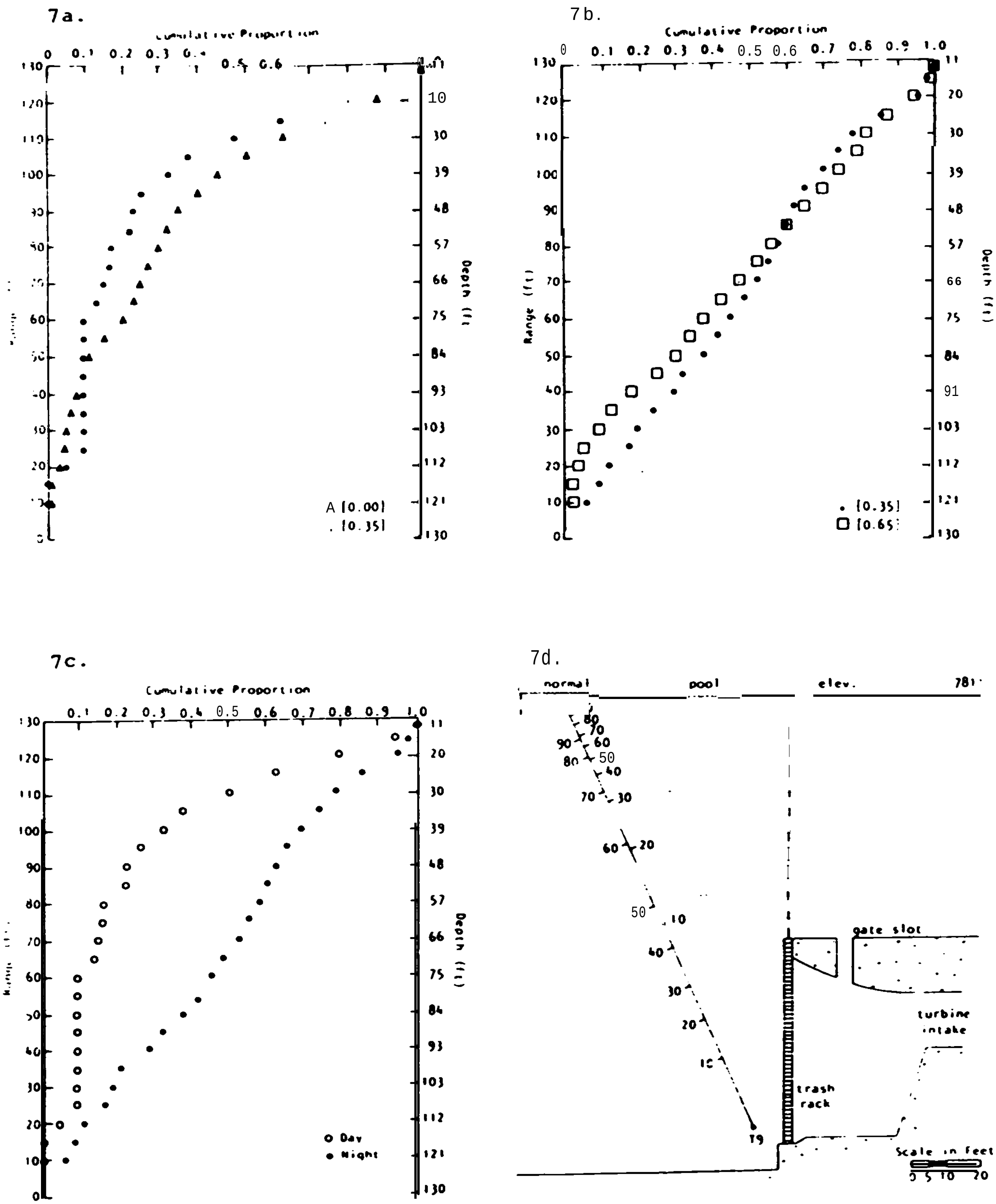


Figure 7. Cumulative vertical distributions of migrants at T9 during Season Block 2 (April 30 - May 25, 1984) at Wells Dam. Range refers to distance from the transducer along the acoustic axis, as shown in (d); (a) for constant day conditions; 0.0 vs. 0.30-0.40 spill proportions; (b) for constant night condition; 0.30-0.40 vs. 0.60+ spill proportions; (c) for constant 0.30-0.40 spill proportions; day vs. night; (d) same data as in (c), but plotted graphically along the acoustic axis. of the transducer.

Table 4. Vertical distribution data from all four pier nose transducers combined. Data were sorted into Spill proportion ranges (0.35=0.30-0.40; 0.45=0.40-0.050; 0.60+->0.60). The data are expressed as cumulative percentages by range from the transducers, which were mounted 125 ftdeep and aimed upward 24° off the face of Wells Dam in 1984.

	Range	DAY				NIGHT			
Block	(ft)	.O	.35	.45	.60+	.o	.35	.45	.60+
1	10	0.0		0.0		0.0		0.0	0.0
1	20	1.8		6.3		3.1		3.7	0.0
1	30	3.6		13.2		3.8		8.1	2.2
1	40	6.0	N	15.3	N	s.4	N	10.8	4.3
1	50	9.0	0	22.9	0	7.S	0	17.3	8.2
1	60	14.0		27.3		12.6		23.7	11.6
1	70	18.2		35.9		14.5		31.2	16.3
1	80	24.1	D	41.3	D	18.2	D	38.0	21.5
1	90	33.1	A	49.9	A	24.0	A	44.3	27.1
1	100	47.3	T	58.5	T	34.4	T	S4.8	38.0
1	110	65.6	A	71.5	A	54.2	A	66.8	ss.4
1	120	86.5		93.s		82.2		89.6	83.7
1	130	100.0		100.0		100.0		100.0	100.0
2	10	0.8	0.0				6.3	0.0	2.6
2	20	3.3	5.1				11.4	1.0	4.0
2	30	4.4	9.0				10.9	8.2	9.0
2	40	7.5	9.0	N	N	N	28.9	16.9	18.5
2	so	11.3	9.0	0	0	0	37.5	27.6	30.0
2	60	20.4	9.0				4S.2	36.3	37.2
2	70	25.1	15.0				52.1	46.6	47.4
2	80	29.2	16.4	D	D	D	58.0	SS.6	56.4
2	90	35.3	23.1	A	A	A	61.9	64.7	64.2
2	100	46.0	32.2	T	T	T	69.2	72.4	73.5
2	110	63.0	49.5	A	A	A	78.0	80.0	81.3
2	120	85.9	79.2				95.2	92.7	94.1
2	130	100.0	100.0				100	100	100
3	10	4.s				5.1			
3	20	8.3				12.8			
3	30	10.8				20.6			
3	40	13.8	N	N	N	27.3	N	N	N
3	so	17.4	0	0	0	33.6	0	0	0
3	60	21.0				38.8			
3	70	2S.6				4s.5			
3	80	31.7	D	D	D	S3.6	D	D	D
3	90	40.3	A	A	A	62.3	A	A	A
3	100	52.8	T	T	T	72.1	T	T	T
3	110	40.3	A	A	A	82.0	A	A	A
3	120	93.9				94.8			
3	130	100.0				100.0			

3.3.2 Horizontal Distribution

At the 4 monitoring locations during all season blocks, highest fish passage (day+night) was observed at T3 (over 36%) and the lowest at T9 (under 9%); fish passage at T5 and T7 was in between that for T3 and T9 (Table 5 and Figures 8a,b). Relatively high passage at the western end of the dam was also observed in 1983. However, the small number of fish detections at T9 differs from the 1983 results(BioSonics 1983).

Tbe comparison of day and night horizontal distributions for Block 2 showed that the trend of high to low passage from west to east was less pronounced during the night than the day (Figure 8a). This was probably due to the large amount of spill in the center part of the dar at night (see Appendix E). During Blocks 1 and 3, day and night horizontal distributions did not differ substantially (Table 5).

The comparison of horizontal distributions for low(0.0) and high (0.45-0.55) spill proportions during Block 2 showed that passage was more uniformly distributed when the spill level was high than when it was low (Figure 8b). Since spill levels were higher at night, these results corroborate the comparison of day and night horizontal distributions.

Table S. Percentages of the total mean number of fish per hour at each forebay monitoring location for day and night during each block.

Block	Day/night	T3	TS	T7	T9	Total
1	D: 0600-2000	18.3	14.3	11.5	4.1	48.2
	N: 2000-0600	18.4	14.4	14.3	4.7	51.8
	Total	36.7	28.7	25.8	8.8	100.0
2	D: 0500-2000	22.8	17.1	13.8	1.3	55.0
	N: 2000-0500	21.4	9.1	13.0	1.5	45.0
	Total	44.2	26.2	26.8	2.8	loo.0
3	D: 0500-2 100	20.5	15.0	11.5	1.2	48.2
	N: 2100-0500	23.3	12.2	14.4	1.9	51.8
	Total	43.8	27.2	25.9	3.1	100.0

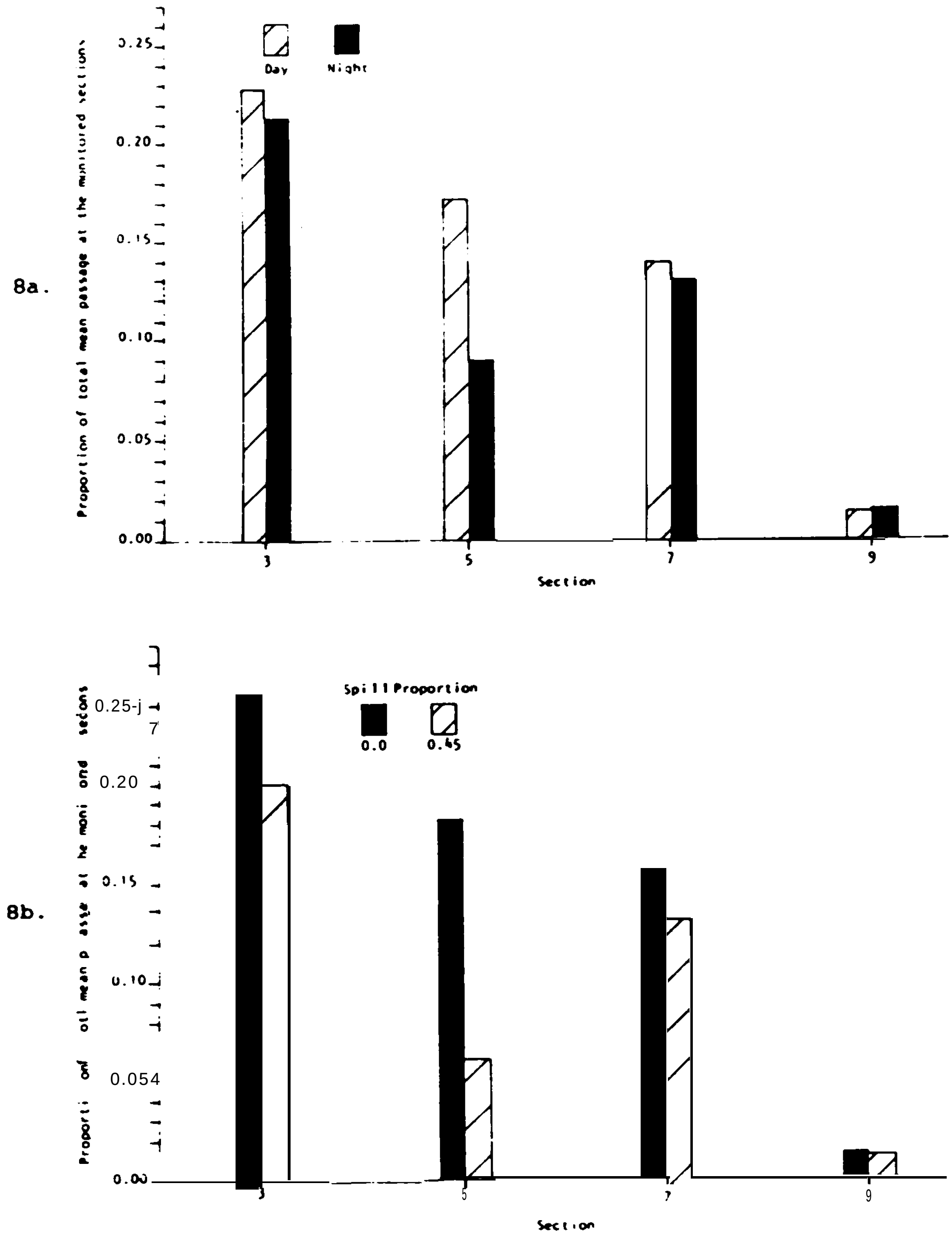


Figure 8. Horizontal distributions of migrants in front of wells Dam for Season Block 2 (April 30 - May 25, 1984) expressed as proportions of total mean fish passage at the four monitored sections. (a) for day vs. night; (b) for 0.0 vs. 0.40-0.50 spill proportions.

3.3.3 Die1 Distribution

During Blocks 1 and 3, mean passage rates were comparable for day and night hours (Table 6). However, during Block 2 the mean fish passage rate during daylight hours was higher than that during night hours (Figure 9 and Table 6).

An estimate of the relative number of fish passing the monitored units during each day or night period was derived by multiplying the mean passage rates for each period by the number of hours of each period. The results showed that the percentage of total passage was much higher during the 14 to 16-h days than the 8 to 10-h nights for all three blocks (Table 6).

In 1983 and in all three blocks in 1984, there were conspicuous dips in passage around dawn and dusk. The 1984 24-h die1 distribution for Block 2 is presented in Figure 9. This pattern could have resulted from changes in dam operations occurring then and/or from fish behavioral responses to sunrise and sunset.

Table 6. Percentages of total mean number of fish per hour and total passage for each day/night period for each season block. Data combined from the four forebay monitoring locations at Wells Dam in 1984.

Block	Day/Night	% of Total Mean #/hr	% of Total
1	D: 0600-2000	48.2	60.8
	N: 2000-0600	51.8	39.2
2	D: 0500-2000	55.0	71.0
	N: 2000-0500	45.0	29.0
3	D: 0500-2100	48.2	69.4
	N: 2100-0500	51.8	30.6

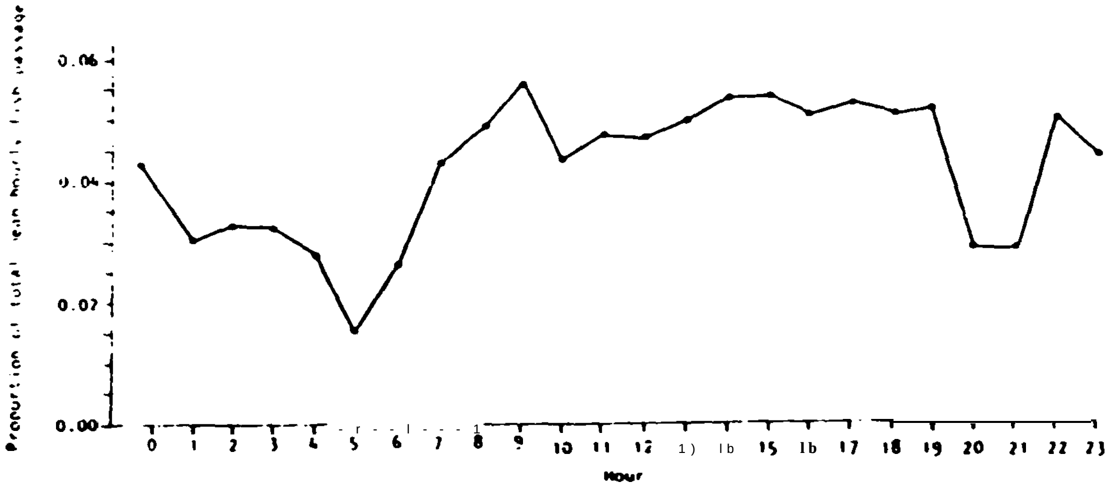


Figure 9. Die1 distribution of fish passage at wells Dam from April 30 to May 25.1984 (PDT).

4.0 summary and Conclusions

The downstream migration of salmon and steelhead smolts at Wells Dam was monitored from April 2 to June 15, 1984. An index of run tiring was reported daily to the Water Budget Center in Portland, Oregon.

The first substantial increase in fish passage occurred on April 25, 1984 due to the chinook released fra the Winthrop hatchery on April 23. During May, run timing was fairly uniform except for peaks on May 2, 14, 18, and 22. The unexpected peak in run size that occurred from May 29 to June 2 could have been caused by juvenile mountain whitefish. However we cannot be certain of this because no net data were collected during the peak in question. Although the proportion of each species varied, chinook passage probably peaked in late April, and steelhead in the first two weeks of Way; sockeye passage was variable throughout the study.

Smolts distributions in space and time were estimated from the same data collected for smolt monitoring. Most downstream migrants near the face of the dam were distributed high in the water column toward the western end of the dam. The horizontal distribution was more uniform at night when there was spill than during the day when there was very little spill. Average hourly passage rates for day and night were similar, so more fish passed the dam during the longer day period than at night.

REFERENCES

Albers, V.H. 1965. Underwater Acoustics Handbook-II. The Pennsylvania State Univ. Press, university Park, Penn. 365 p.

BioSonics, Inc. 1982. Hydroacoustic assessment of downstream migrating salmonids at Wells Dam in 1982. Draft report submitted to Douglas County PUD.

BioSonics, Inc. 1983. Hydroacoustic studies of downstream migrant salmonids at Wells Dam in spring, 1983. Draft report submitted to Douglas County PUD.

Carlson, T.J. 1982. Fixed-aspect hydroacoustic techniques for estimating the abundance and distribution of downstream migrating salmon and steelhead at Columbia River hydropower dams. Paper #108. Proceedings of the Symposium of Fisheries Acoustics, Bergen, Norway.

Carlson, T.J., et al. 1981. Hydroacoustic assessment of downstream migrant salmon and steelhead at Priest Rapids Dam in 1980. univ. of Wash. Applied Physics Lab., Seattle, WA. Report No. APL-UW 8016.

Ehrenberg, J.E. 1982. A review of in situ target strength estimation techniques. Paper #104. Proceedings of the Symposium on Fisheries Acoustics, Bergen, Norway.

Urick, R.J. 1975. Principles of Underwater Sound. McGraw-Hill Book Co., San Francisco. 384 pp.

APPENDIX A: Hydroacoustic System Equipment Operation, and Calibration

Equipment Description

The hydroacoustic monitoring study at Wells Dar in 1984 required one BioSonics system. The system (Figure Al) consisted of the following components: high-frequency transducers (420 kHz) with cable, an echo sounder/transceiver, a multiplexer/equalizer, one or two chart recorders, and an oscilloscope. A reel-to-reel tape recorder was also available for recording the echo sounder output for later laboratory analysis. Specific manufacturers and model numbers of the electronic equiprent used are listed in Table Al. The hardware parameters used in 1984 are presented in Table A2.

Equipment Operation

The hydroacoustic systems works as follows. When triggered by the Model 101 Echo Sounder, a high-frequency transducer emits short sound pulses in a relatively narrow beam aired toward an area of interest. As these sound pulses encounter fish or other targets, echoes are reflected back to the transducer which then reconverts the sound energy to electrical signals. The signals are then amplified by the echo sounder at a 40 log(R) time-varied-gain (TVG) to compensate for the loss of signal strength due to absorption and geometric spreading of the acoustic beam with distance from the transducer. Thus, equally sized targets produced the same signal amplitudes at the echo sounder receiver output regardless of their distance (range) from the transducer. The range of each target from the transducer is determined from the time it takes the sound pulse and echo return to travel that distance (velocity of sound in freshwater = 1445 m/sec).

The echo sounder relays the returning TVG-amplified signals to the chart recorder, oscilloscope, and tape recorder. The return signals are visually displayed on the oscilloscope to observe echo strength and echo duration. Returns from individual fish are recorded on the chart recorder's echogrars which provide a permanent record of all targets detected throughout the study. The threshold circuit on the chart recorder is adjusted to eliminate signals less than the echo levels of interest.

The Model 151 Multiplexer/ Equalizer **(MPX/EQ)** permits a single echo sounder to automatically interrogate up to 16 different transducers in an operator-specified sequence. The appropriate transducers and equalizes the return signals to compensate for the differing receiving sensitivities resulting from varying cable lengths and transducer characteristics.

System Calibration

Each acoustic system at Wells Dam was calibrated before the study began. Calibration assured that an echo from a target of known acoustic size passing through the axis of the acoustic beam produced a specific output voltage at the echo sounder. Based on the calibration information, the adjustable print threshold on the chart recorder was set so that it would print signals from targets larger than -50 dB on the acoustic axis of the transducer. This minimum target strength corresponded to the smallest juvenile salmonids sampled during the study. The calibration information was also used to equalize (using the MPX/EQ) the system sensitivity for each receiving channel. A system calibration at the end of the season verified that the sensitivities had remained constant throughout the study. A detailed description of the calibration of hydroacoustic systems can be found in Albers (19651 and Urich (19751.

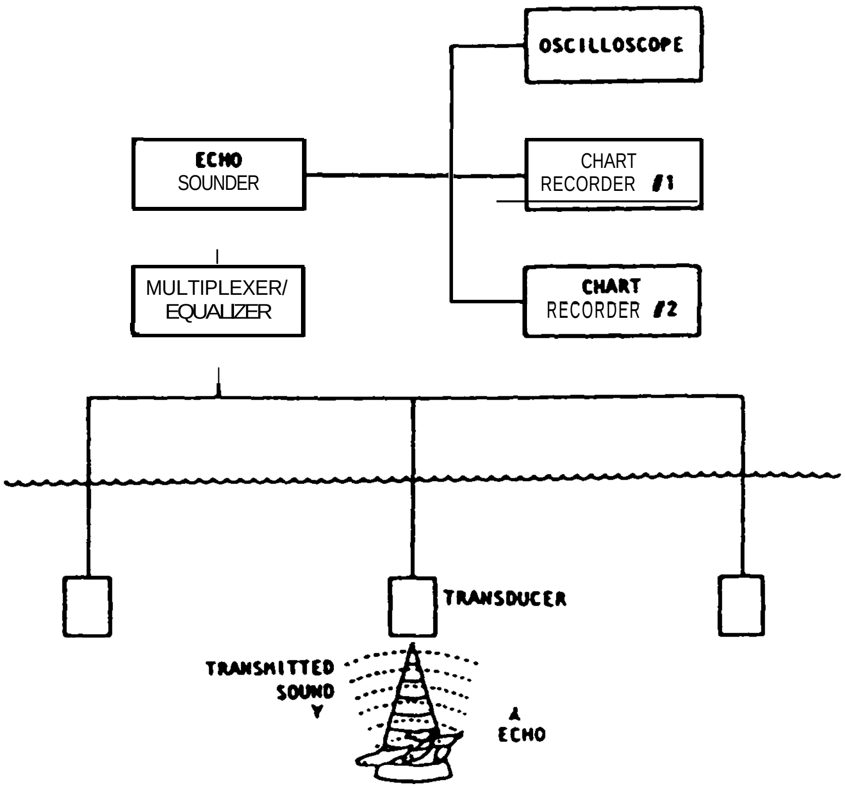


Figure Al. Block diagram of primary data collection system used at Wells Dam in 1984.

Table A1. Model numbers manufacturers, and serial numbers of electronic equipment used by BioSonics, Inc. at Wells Dam, spring 1984.

Model Number/ Equipment	Manufacturer	Serial Number
Model 101 (420 kHz) Echo Sounder	BioSonics, Inc.	101-81-010 101-83-030
Model 151 MPX/EQ Multiplexer/Equalizer	BioSonics, Inc.	151-83-006
Model X-MPX Uultiplexer	BioSonics, Inc.	UPX-81-004
Model X-EQU	BioSonics, Inc.	EQ-82-010
Model C Model E Chart Recorders	Ross Laboratories, Inc. modified by BioSonics, Inc.	2013-I 07 2120-I 18
Model 1600s Chart Recorders	EPC, Inc.	
EFC Chart Recorder Interfaces	BioSonics, Inc.	EX-83-001 EPC-83-005
Transducers	Advanced Transducer Technology (BioSonics)	
Model 2215 Oscilloscope	Tektronix	

Table A2. Hydroacoustic system parameters used for studies at Wells Dam in 1984.

<u>Echo Sounder</u>
Transmit frequency: 420 kHz
Transmit power: 0 dB
Band width: 5 kHz
Pulse width: 0.3 msec
TVG: 40 log(R)
Trigger source: Ross chart recorder
<u>Chart Recorder - Ross</u>
Paper speed: 4
Range select: O-150 ft
Threshold: 0.1 volts

APPENDIX B: data Acquisition Procedures

Migrant Detection Criteria

Echogram traces had to satisfy two criteria to be classified as fish: 1) the strength of target echoes had to exceed a predetermined threshold; and 2) the targets had to be detected by consecutive acoustic pulses (redundancy).

The hydroacoustic systems were calibrated so that the chart recorder marked only targets with echo strengths greater than -50 dB at the acoustic axis of each transducer. This target strength threshold was chosen so that even the smallest outmigrant salmon and steelhead returned an echo strong enough to mark the echogram.

At least four successive echoes were required for a target to be classified as a fish. Most of the fish observed were detected more than four times in succession. This high redundancy occurred because of the relatively wide beamwidths of the transducers and the high pulse repetition rates. This redundancy criterion enhanced fish detectability in the presence of background interference. Further details of fish detection criteria for fixed-location hydroacoustics can be found in Carlson, et al. (1981).

Based on echogram "trace types. (i.e., the pattern of marks produced by successive detections), fish were classified as either 'migrants" or 'wallowers". Wallowers produced marks consistent with large resident fish milling about in the forebay. Migrant trace-types exhibited change-in-range consistent with the smaller smolts. Only fish classified as migrants were included in the analyses.

Background Interference Level

The background interference level on the echograms of each interrogation period was rated on a scale of 1 to 5. Interrogation periods with the highest interference levels (4 and 5) were not included in data analysis. For the spring 1984 studies at Wells Dam, less than 5% of all interrogation periods were excluded because of excessive interference.

Data Entry and Storage

Microcomputers were used for data storage and analysis. Data from individual fish detections recorded on the echograms were transformed to computer data files using a digitizing pad and appropriate software. For each fish detected passing through the acoustic beam, a technician used the digitizing stylus to record the following:

time of entrance
time of exit
range at entrance
range at exit
trace type

The following information was recorded for each interrogation period:

date
start tire of transducer interrogation
duration of transducer interrogation
transducer location
transducer depth
transducer beamwidth
transducer orientation
background interference level

APPENDIX c: Data Reduction and Horizontal and Die1 Distribution Methods

Data Selection

Two criteria were used to select the data for the various analyses. First, all fish detections from interrogation periods with excessive background interference were eliminated, as explained in Appendix B. Second, based on trace type classification, all non-migrant fish ('wallowers') were excluded. The remaining fish detections were used in the analyses.

Range of Fish

For outmigrant (1), the range from the transducer (R_i) was the mid-point range of the echo trace as calculated by:

$$R_i = \frac{R_{in} + R_{out}}{2}$$

where R_{in} and R_{out} are the ranges at which the fish entered and exited the acoustic beam, respectively.

Weighting Factor

Since only a portion of the cross-sectional area at a sampling location was ensonified, individual fish detections were multiplied by a weighting factor to estimate the total relative number of fish passing that location at that particular range and time. To account for the cone-shaped geometry of the acoustic bear, the weighting factor was defined as the ratio of the width at the sampling location to the width of the acoustic beam at the range of detection. (The width for the pier nose sampling location was 90 ft.) The weighting factor was:

$$W_{ij} = \frac{I_j}{2R_i \tan(\Theta/2)}$$

where W_{ij} = weighted observation of fish (i)

I_j = width of location (j)

Θ = nominal beamwidth of transducer

R_i = range of fish (i) from transducer.

Thus, fish detected closer to the transducer were weighted more (to represent more fish) than those detected further away. All subsequent analyses, except vertical distributions, were based on these weighted fish detections.

For the vertical distribution analysis, a similar but simpler weighting formula was used since estimates of passage were not necessary for that analysis (see Appendix D).

Fish Passage Indices

An hourly estimate of fish passage (#/hr) at location (j) was computed as:

$$F_{jh} = \sum_{j-l}^{n} W_{ijh} \times 60/t_{jh}$$

where F_{jh} = number of fish per hour at location (j) during hour (h)

W_{ijh} = weighted fish (i) at location (j) during hour (h)

t_{jh} = total number of minutes in hour (h) that location (j) was sampled

n = total number of migrant detections at location (j) during hour (h).

Horizontal Distribution Methods

Two types of horizontal distribution analyses were performed for each season block (April 2 to 29, April 30 to May 25, and Hay 26 to June 15). First, separate horizontal distributions of fish for day and night were examined. Second, separate horizontal distributions were examined for specific ranges of the spill proportion (0.0 and 0.45-0.55).

Horizontal distributions were obtained from the mean hourly fish passage estimates at each location, as derived above. For the specific day and night periods and operating conditions, all of the #/hr estimates for each interrogation at a given location were averaged. This produced estimates of mean passage per hour for each of the pier nose transducers (T3, T5, T7, and T9). Thus, hourly passage estimates (#/hr) at each location were the primary statistics for the horizontal distribution analysis. The results are expressed as the ratios of passage (#/hr) at each location to the total passage for all four locations.

Die1 Distribution Methods

The die1 distribution in fish passage was presented as 24 hourly means and by comparing passage during day and night periods. The 24 hourly means were derived by obtaining total relative passage estimates (T3+T5+T7+T9) per hour, sorting them by hour of the day, and then averaging each of each 24 separate sets of data over all days for each block separately. Fish passage during day and night periods was estimated by averaging the total relative passage estimates for the hours within a given time period.

APPENDIX D: Vertical Distribution Functions

Weighti. g Procedures

Before estimating the vertical distribution of fish, it was necessary to adjust the fish detections for differences in the probability of detection at different distances from the transducer. Because the diameter of the ensonified volume increased in direct proportion to the range from the transducer, each observation was weighted by:

$$V_i = k/B_i$$

where V_i = weighted fish observation (i) for vertical distribution analysis

k = expansion width (in ft), constant over all depths

B_i = beam diameter (in ft) at the range of fish detection (i)

This formula assigns more weight to targets closer to the transducer than those further away. This weighting formula was applied only for the vertical distribution analyses. (See Appendix C for the weighting formula used for fish passage estimates.)

Vertical Distribution Estimation

The vertical distribution of fish with respect to range was summarized with a cumulative distribution function. The results are presented as the cumulative percentage of fish occurring within a given range from the transducer. The formula applied was:

$$P(r) = 100 \sum_{j=min}^{r} \sum_{i=1}^{n_j} v_{ij} \Big/ \sum_{j=min}^{max} \sum_{i=1}^{n_j} v_{ij}$$

where $P(r)$ = the percentage of fish occurring between the transducer and range (r)

v_{ij} = weighted fish observation (i) at range (j)

n_j = number of fish observed at range (j)

min = minimum observed fish range

max = maximum observed fish range

r = a specified range.

APPENDIX E: Methods and Results for Project Discharge and Dan Operations

E.l Introduction

Project discharge and operations data are essential for understanding the distribution of smolts at the dam. This appendix documents 1984 water flows and describes patterns of flow to help interpret fish data.

E.2 Methods

DCPUD provided data on monthly project discharge for 1984 and for the months of April, nay, and June for the previous 15 years (1969-1983). The following hourly dam operations data for the period April 2 to June 14, 1984 were also obtained: total project discharge, total spill discharge, total turbine discharge, total spill gate height, individual gate heights, and individual turbine loadings. These data were used to compare the 1984 spring runoff to that of previous years and to describe patterns of discharge through the dam in 1984.

Daily estimates of total project discharge were made by averaging the hourly estimates of total project discharge (in kcfs) and then multiplying by 86,400 seconds/day.

Hourly average flow (in kcfs) at a particular turbine was estimated by multiplying total turbine discharge by the ratio of that turbine's loading (megawatts) to total project loading.

Hourly average flow (in kcfs) at a particular spill bay was estimated by multiplying total spill discharge by the ratio of that spill bay's gate height to the sum of all gate heights. (The assumption that the relationship between gate height and flow is linear in the ranges of operation has been confirmed from data provided by R. Barrutia of DCPUD.)

Horizontal distributions of turbine and spill flows were obtained by averaging the hourly results at the individual locations.

The die1 distributions of turbine and spill flows were obtained by separating data from each of the 24 daily hours and then averaging the hourly estimates for each season block (April 2 to 29, April 30 to May 25, and Hay 26 to June 15).

The "spill proportion' is defined as spill discharge divided by spill plus turbine discharge. Spill proportions were calculated for the dam as a whole and for each section. This information, estimated hourly, was used in analyzing the effects of dam operations on the vertical and horizontal distributions of the smolts.

E-3 Results

E-3.1 Project Discharge

Mean daily project discharge for April 1984 was 136.7 kcfs or 114% of the 15-year average. For May it was 132.0 kcfs or 84%, and for June it was 131.6 kcfs or 75%. In volume per day, project discharge ranged between 6.7 and 15.6 million ft^3; the mean was 11.4 million ft^3/day.

The higher than normal April flows at Wells resulted from the draw-down of Grand Coulee Dar in anticipation of a larger runoff than actually occurred. The lower actual runoff was because spring 1984 turned out to be cooler than usual. Flows at Wells were lower than normal in May and June because most of the spring runoff that was not used for power generation at Chief Joseph and Grand Coulee dams was stored at those dams.

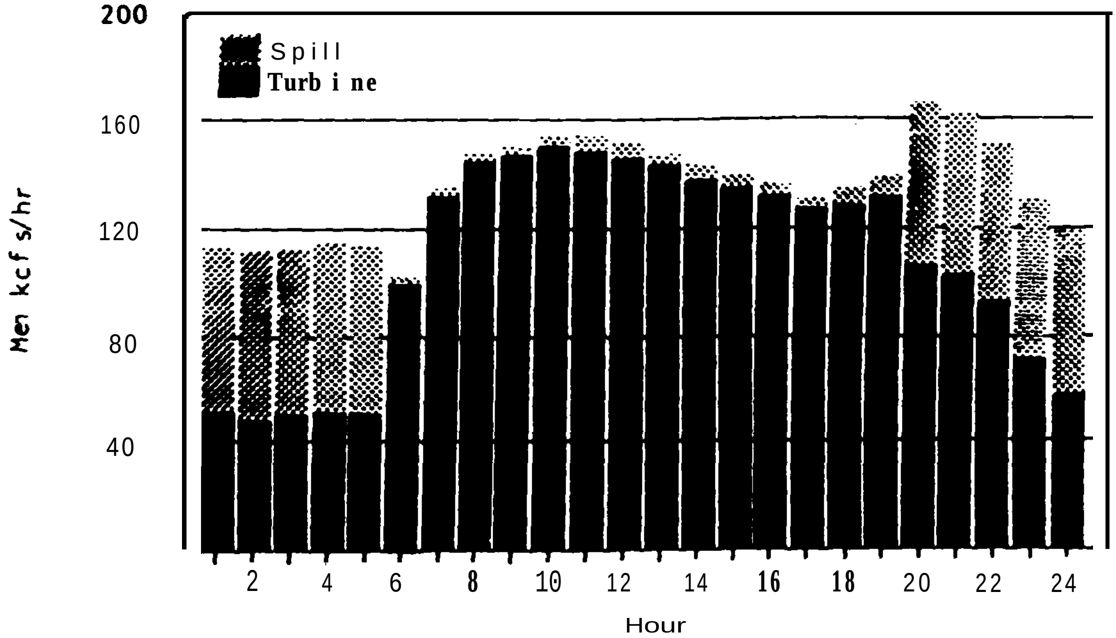
E.3.2 Dam Operations

Operations data for Wells Dam during spring 1984 are presented graphically for the period April 30 to May 25 (Figures El, E2, and E3). This was when: most of the outmigrant salmon and steelhead passed the dam; the prototype study took place; and FERC spill occurred. Tabular operations data for April 2-29 and May 26-June 15 can be found in Section E3.3 of this appendix.

In 1984, the FERC spill period at Wells was from April 26 to May 25. FERC spill volumes for April 26-29 were 251 of total flow into the reservoir (notprojectdischarge) for the previous day. For May l-24, FERC spill was 20%. FERC spill occurred mostly at night (2000-0600 h) in the center part of the dam (Figures E1, E2, and E3). During FERC spill, over 50% of the flow at Sections 3, 4, 6, and 7 was spill (Figure E2).

Turbine discharge was greatest during daylight hours and was distributed evenly across the dam (Figures El and E3). During weekdays between 0700 and 2200 h, power demand was at its highest. Turbine discharge was a larger component of total project discharge than spill discharge, even at night (Figure El).

Hourly project discharge was somewhat greater during day than night and was characterized by slight dips around 0600 and 1700 h (Figure El). The horizontal distribution of spill plus turbine discharge (i.e., section discharge) was relatively uniform (Figure E3).



Pigure El. Die1 distribution of total project discharge (mean kcfs/hr) with spill and turbine shaded separately, from April 30 to May 25, 1981 at Wells Dam.

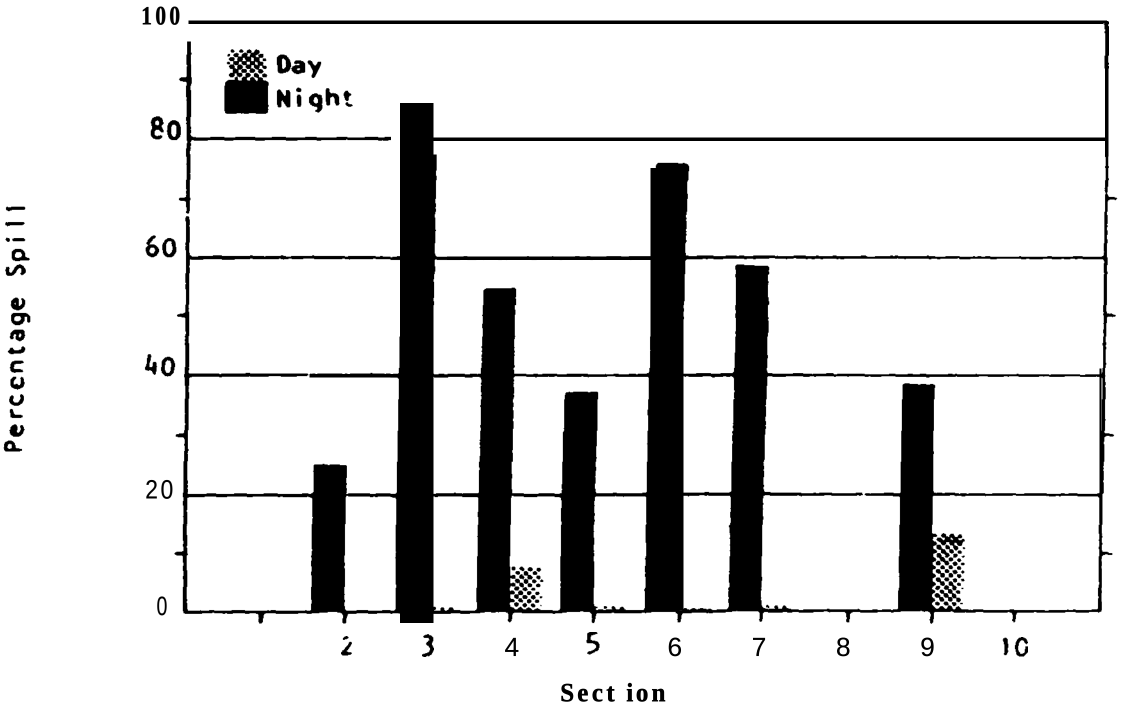


Figure E2. Horizontal distribution of the proportion spilled at each "section" of the dam (mean kcfs spill/(mean kcfs spill + turbine)) for day (0500-2000 h) and night (2000-0500 h) separately from April 30 to May 25, 1984 at Wells Dam.

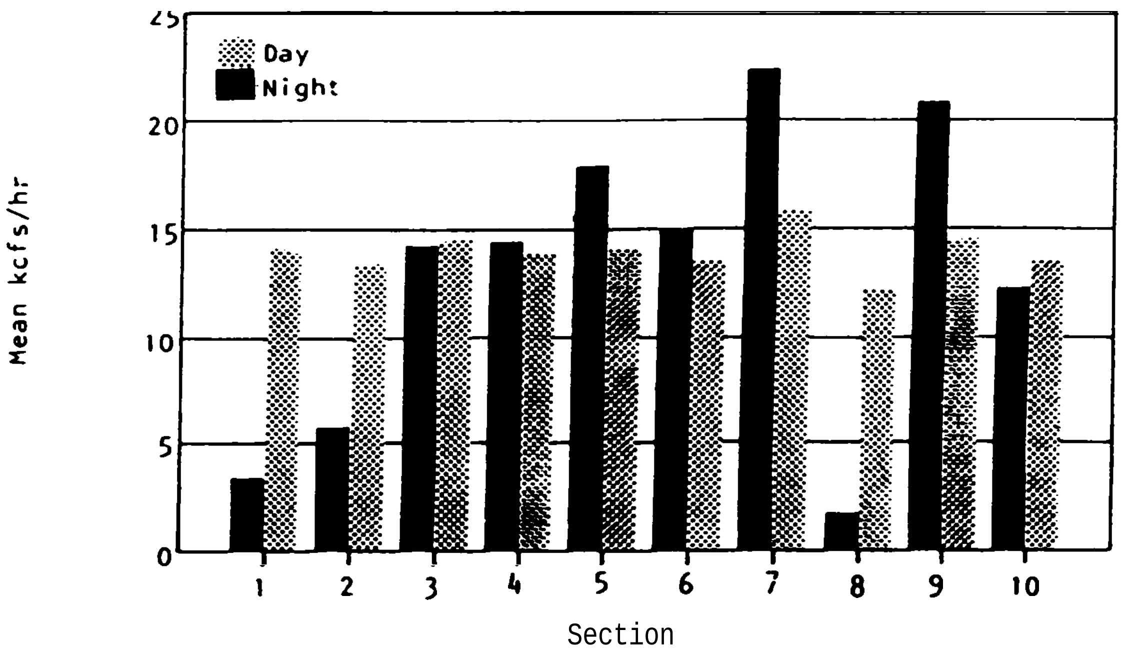


Figure E3. Horizontal distribution of combined spill and turbine discharges (mean kcfs/hr) for day (0500-2000 h) and night (2000-0500 h) separately from April 30 to nay 25, 1984 at Wells Dam.

E.3.3 Tabular Results for all Season Blocks

The results describing the horizontal distribution of flow, the horizontal distribution of the spill proportion, and the die1 distribution of total project discharge are presented in Tables El, E2, and E3, respectively. The results are for each season block separately.

Table El. Horizontal distribution of mean hourly spill + turbine kcfs for day and night separately for each seasonal block.

	SEASONAL TIME BLOCK					
	1 (4/4-4/29)		2 (4/30-5/25)		3 (5/26-6/14)	
SECTION	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
1	3.43	2.20	14.18	3.49	7.51	5.47
2	14.75	14.36	13.35	5.91	14.23	10.45
3	16.82	17.18	14.50	14.35	15.88	10.95
4	14.22	13.58	13.79	14.46	11.19	7.49
5	13.66	16.92	14.20	17.94	13.95	11.66
6	16.20	17.34	13.52	14.94	13.32	7.47
7	19.09	22.45	15.85	22.26	16.61	15.29
8	10.53	6.84	12.06	1.82	9.49	4.18
9	12.72	12.84	14.41	20.88	13.68	7.03
10	12.15	9.50	13.54	12.35	10.74	6.14

Table E2. Horizontal distribution of mean hourly spill proportion for day and night separately for each seasonal block.

	SEASONAL TIME BLOCK					
	1 (4/4-4/29)		2 (4/30-5/25)		3 (5/26-6/14)	
SECTION	DAY	NIGHT	DAY	NIGHT	DAY	NIGHT
1	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.25	0.00	0.00
3	0.18	0.38	0.01	0.85	0.00	0.00
4	0.10	0.21	0.08	0.55	0.04	0.03
5	0.20	0.38	0.01	0.37	0.03	0.04
6	0.17	0.44	0.01	0.75	0.04	0.06
7	0.15	0.34	0.01	0.58	0.00	0.01
8	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.11	0.14	0.38	0.01	0.04
10	0.00	0.00	0.00	0.00	0.00	0.00

Table E3. Die1 distribution of mean hourly spill, turbine and total project discharge in kcfs for each season block separately, spring 1984 Wells Dam.

	SEASONAL TIME BLOCK								
	1 (4/4-4/29)			2 (4/30-5/25)			3 (5/26-6/14)		
HOUR	SPIL	TRBN	DSCHRG	SPIL	TRBN	DSCHRG	SPIL	TRBN	DSCHRG
				(kcfs)					
1	36.3	84.1	120.4	62.1	51.7	113.8	0.3	64.2	64.6
2	34.2	83.8	117.9	62.1	49.9	112.0	3.2	64.9	68.1
3	36.3	84.3	120.7	62.1	50.0	112.1	3.2	65.4	68.6
4	36.3	89.3	125.6	62.1	51.9	114.0	3.2	66.9	70.1
5	34.0	89.2	123.2	62.1	51.9	114.0	3.2	74.2	77.4
6	11.6	106.1	117.7	2.5	99.3	101.8	1.6	92.6	94.2
7	8.1	120.0	128.1	2.5	131.6	134.1	1.5	120.5	122.0
8	8.1	135.4	143.5	1.8	145.2	146.9	1.5	140.0	141.5
9	8.1	141.8	149.9	1.6	147.6	149.2	2.2	148.6	150.8
10	9.0	137.0	146.0	2.8	150.9	153.7	2.3	152.4	154.7
11	9.2	132.9	142.1	3.9	149.1	153.0	2.8	147.6	150.4
12	10.7	127.7	138.4	4.8	145.7	1SO.6	2.1	138.8	140.9
13	16.8	118.4	135.0	4.3	143.1	147.4	2.0	126.9	129.0
14	19.9	114.8	134.7	4.4	138.9	143.2	1.8	118.8	120.6
15	23.1	111.4	134.5	4.3	134.5	138.8	1.5	113.3	114.8
16	22.4	112.6	135 0	3.0	132.2	135.2	10.3	113.7	124.0
17	21.4	117.2	138.6	2.5	127.5	130.0	1.6	115.0	116.6
18	14.2	124.2	138.9	5.3	128.6	133.8	0.1	129.1	129.2
19	8.1	137.7	145.7	7.4	130.6	138.0	0.1	137.3	137.4
20	26.0	132.6	158.6	59.8	105.7	165.5	0.3	137.8	138.2
21	35.2	118.2	153.4	59.8	101.7	161.4	0.3	132.3	132.6
22	39.4	102.6	142.1	58.8	92.5	151.4	8.3	131.8	140.0
23	39.4	90.9	130.3	58.8	71.2	130.0	0.3	95.7	96.0
0	36.3	84.6	120.9	62.1	57.1	119.2	0.3	68.4	68.8

Appendix F. Run tiring index values (I/location/day) for 1982, 1983 and 1984. The 1982 index is calculated for the hours 1600 to 0700, 1983 for the hours 0800 to 0800 and 1984 0000 to 0000. Note the 1982 index is calculated for a 16 hr period, and 1983 and 1984 indices are calculated for 24 hr periods.

Date	1982 Index	1983 Index	1984 Index	Date	1982 Index	1983 Index	1984 Index
April 2			752	May 18	2227	1174	2658
3			647	19	2381	2020	1941
4		101	488	20	1946	1342	1383
5		101	526	21	1101	2484	1605
6		80	528	22	836	2575	1930
7		181	616	23	868	998	1407
8		121	452	24	1336	778	1165
9		177	410	25		269	1276
10		73	421	26		215	1356
11		49	419	27			1301
12	94	84	41s	28			2089
13	284	93	405	29			3808
14	1874	85	563	30			1852
15	242	111	15s	31			2246
16	2114	217	510	June 1			2544
17	3269	230	601	2			2341
18	2077	494	693	3			1459
19	1042	865	430	4			1337
20	1570	1721	365	5			960
21	2109	2737	169	6			1120
22	1759	3773	249	7			1136
23	1397	5003	458	8			1411
24	881	1693	925	9			1115
2s	1472	1793	1429	10			1368
26	992	1544	2349	11			1711
27	1019	1211	1769	12			1225
28	1134	1400	2218	13			1726
29	562	173s	1335	14			1374
30	1040	3177	1059	15			1108
May 1	499	3256	10S8				
2	107	2917	3818				
3	581	3221	1572				
4	282	3369	1247				
5	492	2680	1144				
6	162	2263	1001				
7	757	1965	1116				
8	561	1790	998				
9	697	2014	1276				
10	1025	1950	828				
11	604	2153	802				
12	633	1069	817				
13	1787	2239	1143				
14	781	2353	2745				
15	718	2153	1446				
16	8 %	1289	1426				
17	2880	1531	1969				